THREE ARCHITECTURES FOR THE NEW MILLENNIUM
AT THE END OF CARBON

Toward a Temporal Theory of Architectural Sustainability

XEMA GATNAU

Abstract

Sustainable architecture cannot be determined solely by the materials it uses, but by the relationship between material, duration, maintenance, and replacement cycle. A building is not sustainable merely because it uses natural materials, nor does it automatically cease to be sustainable because it uses heavy or industrial materials. What is decisive is the coherence between the initial impact of a construction and the period during which that impact remains justified.

This text proposes three major models for future architecture: renewable or carbon-sink architecture, based on biogenic, recyclable, compostable, or low-impact materials; ultrapermanent architecture, based on highly resistant materials with a high initial cost - such as concrete, stone, ceramics, or stainless steel - whose legitimacy depends on extreme duration; and stratified architecture, which combines different temporal layers within the same building: renewable skins, replaceable services, and long-lasting structural cores.

The central thesis is that time must become a fundamental category of architectural sustainability. The architecture of the future will not be sustainable merely because it is light, nor merely because it is robust, but because it correctly aligns each material with its duration, maintenance, and fate. What is unsustainable will not necessarily be what is heavy or perishable, but what combines high material impact with a short life, rapid obsolescence, and an absence of temporal responsibility.

Keywords: sustainable architecture, duration, embodied carbon, ephemeral architecture, biogenic materials, concrete, stainless steel, straw, timber, permanence, temporal stratification, Return on Environment.

1. Introduction: Time as the Forgotten Criterion

Architectural sustainability is often discussed in terms of materials: timber versus concrete, straw versus steel, earth versus industrial materials, natural systems versus high-impact systems. This opposition is understandable, but incomplete. No material is sustainable in an absolute and isolated sense. Its ecological value depends on how it is obtained, transformed, transported, and maintained, how long it lasts, and what happens to it when it is no longer useful.

In this text, the "end of carbon" does not, of course, mean the disappearance of the chemical element, but the gradual end of an economic model founded on the extraction, combustion, and massive release of fossil carbon. The new millennium at the end of carbon will be one in which architecture must answer for the energy and matter it immobilises, but also for the period during which it prevents new extraction, emissions, and reconstruction.

The common mistake is to separate matter from time. A building is judged by its initial impact, its ecological appearance, or the type of material used, but the question is not always asked of how long that material will justify its presence in the world. Lightweight architecture can be irresponsible if it is constantly replaced. Heavy architecture can be reasonable if it lasts for centuries. Apparently natural architecture can be false if it depends on excessive replacement cycles, long-distance transport, or polluting treatments. Mineral or industrial architecture can be defensible if it prevents demolition, reconstruction, and waste over generations.

Therefore, the central question should not only be: what is a building made of?

What duration does it promise, what cost does it demand, and for how long is that cost justified?

This text proposes a temporal theory of architectural sustainability. Future architecture will have to choose among three major possibilities: to be renewable and short-cycle but materially innocent; to be ultrapermanent and extremely long-cycle; or to be stratified, combining layers of different duration within the same construction system.

2. First Path: Renewable or Carbon-Sink Architecture

The first path is renewable, biogenic, or carbon-sink architecture. It is based on materials such as straw, timber, cork, hemp, plant fibres, earth, lime, or other low-impact systems capable of storing carbon, biodegrading, being recycled or composted, or returning to the material cycle with reduced damage.

This architecture does not necessarily need to promise a thousand years. Its legitimacy does not depend on extreme permanence, but on the cleanliness of its cycle. If a material grows, absorbs carbon, requires little energy to transform, can be dismantled without major damage, and can be reused or returned to the earth, then its shorter duration may not be a defect. It may form part of a coherent ecological logic.

In this model, periodic replacement is not necessarily obsolescence. A straw skin, a planted roof, a timber enclosure, or a layer of natural fibres may be renewed if its replacement does not entail significant new material violence. Renewable architecture accepts short duration, but only when that short duration is integrated into a regenerative cycle.

Its main virtue is material lightness. Its main danger is the aesthetics of ecology. Not everything that looks natural is sustainable. Straw or timber construction may be irresponsible if it is poorly designed, inadequately protected against moisture, too short-lived, impossible to maintain, chemically overtreated, or transported over

excessive distances. Renewable architecture is legitimate only if its entire cycle is honest.

It is not enough to appear biodegradable. It must be biodegradable within a real material system.

3. Second Path: Ultrapermanent Architecture

The second path is ultrapermanent architecture. It begins from the opposite premise: if materials with a high initial impact are used, those materials must last for a very long time. Concrete, stone, brick, ceramics, stainless steel, or other robust systems should not be used to produce short-cycle buildings. Their justification depends on their duration.

In this model, sustainability does not come from lightness, but from temporal amortisation. A concrete structure may be ecologically obscene if it is demolished after thirty years. But it may acquire another legitimacy if it is designed, built, maintained, and protected to last two hundred, five hundred, or one thousand years. The problem is not simply the use of concrete, steel, or mineral materials. The problem is using them to manufacture obsolescence.

This criterion also applies to apparently minor auxiliary structures - a barbecue or grill house, a small domestic pavilion, or an annex containing a bathroom. If they are built with high-impact materials, their secondary character does not exempt them from being conceived as part of a genuinely durable system.

Ultrapermanent architecture proposes a simple ethical rule:

The greater the ecological cost of a material, the greater the duration demanded of it.

Applying the criterion used for renewable architecture in reverse, it is likewise not enough for a construction to appear durable. It must be durable within a durable material system: structure, joints, protection, repairability, and maintenance must form a continuity capable of sustaining the building's temporal promise.

3.1. ROE: Return on Environment

The environmental footprint of architecture should not be judged solely at the moment of construction. Just as economics uses return on investment to compare an initial sacrifice with the returns obtained later, a long-term environmental indicator can be proposed: Return on Environment (ROE). The term is used here propositionally, not as an already standardised metric; nor should it be confused with the customary financial use of the same initials for Return on Equity.

ROE expresses the accumulated environmental return of a material decision. A solution may produce a relatively high initial carbon footprint and nevertheless achieve a better environmental result if, over centuries, it avoids demolition, reconstruction, structural replacement, new transport, additional consumption of raw materials, and repeated waste generation. The initial environmental investment is therefore judged in relation to the future burdens it succeeds in preventing.

Conceptually, ROE over a time horizon T can be understood as the relationship between accumulated environmental benefits - avoided emissions, saved resources, stored carbon, and reconstructions not undertaken - and the total impacts assumed - initial construction, maintenance, replacements, and end of life.

$$ROE_t = \text{Environmental benefits accumulated up to T} / \text{Environmental impacts accumulated up to T}$$

The formula does not yet seek to establish a universal metric or erase the differences among types of impact. Its function is to organise the reasoning: it requires solutions to be compared within an explicit time horizon and assumptions about service life, maintenance, and replacement to be justified. It can also be used marginally, comparing the additional ROE of a more robust alternative with that of a shorter-lived one.

Ultrapermanent architecture does not merely seek to minimise pollution on the day of construction. It seeks to minimise the accumulated long-term footprint and maximise ROE. This may justify a larger initial material investment when that investment prevents the same function from having to be rebuilt repeatedly. Duration thus ceases to be an ornamental quality and becomes a form of environmental performance.

A heavy building must have a vocation of inheritance. It must be repairable, maintainable, transmissible, and usable by generations that did not participate in its construction. It must be designed to age, not to be replaced. Its value does not lie in continuous change, but in remaining with sufficient dignity for its maintenance to make sense.

This path does not defend rigidity of every kind. Permanent architecture can fail if it becomes useless, hermetic, excessively specific, or impossible to care for. Permanence is not achieved through mass alone. It requires form, programme, maintenance, legal custody, and social necessity. A building may be robust and still not deserve to last.

Ultrapermanent architecture is justified only if its duration is material, functional, symbolic, and institutional.

4. Third Path: Stratified Architecture

The third path is stratified architecture. It does not choose absolutely between the renewable and the permanent, but organises the building into different temporal layers. It recognises that not all elements of a construction should last for the same length of time. A skin may last a few years; a service system, a few decades; an enclosure, several generations; a structure, centuries.

Stratified architecture combines short-cycle materials with long-duration cores. It may have an exterior skin of straw, timber, or plant fibres, renewable and compostable; accessible and replaceable services; repairable enclosures; and a main structure of concrete, stone, ceramics, or stainless steel intended to last for centuries.

The exterior skin need not be materially pure or composed exclusively of plant fibres. It may incorporate a plastic epidermis: membranes, sheets, or polymer components selected to protect the underlying straw or timber layers from moisture, radiation, wind, or wear. The presence of plastic does not in itself invalidate the logic of the system if its quantity, durability, repairability, and final destination are justified and if it substantially prolongs the useful life of the biogenic layers it protects.

This model avoids two opposing errors. The first is believing that everything must be biodegradable and temporary. The second is believing that everything must be heavy and eternal. Responsible architecture does not demand the same duration from all its components. It demands that each layer know its time, function, maintenance, and material fate.

A straw skin does not fail because it lasts for a short time if its function is to protect, shade, insulate, or signify during a brief cycle and then return to the material cycle. A concrete structure does fail if it lasts only a short time, because its material cost demands a greater temporal promise. A technical service does not need to last a thousand years, but it must be replaceable without destroying the building. A door, a joint, a roof, or a skin may be renewed; the structural core must organise those renewals.

Stratified architecture resembles an organism more than a homogeneous object. The resistant core acts as a skeleton: solid, deep, and intended to remain. The outer layers act as skin or epidermis: lighter, more perishable, renewable, and sensitive to environmental variation. As in a body, greater permanence is concentrated within, while the surface is repaired, replaced, and adapted without destroying the continuity of the whole.

This analogy is not merely rhetorical. It entails physically separating the layers, allowing ventilation and drying, making connections accessible, and preventing the

renewal of a cladding layer from reaching the structural core. Temporally hierarchical architecture must prevent the ageing of the epidermis from becoming a pathology of the skeleton.

Stratified architecture is, in this sense, an architecture of temporal hierarchies.

Its question is not: which material is good?

What duration corresponds to each material?

5. The Worst Scenario: High Impact and Short Life

The most unsustainable condition is not necessarily heaviness. Nor is it necessarily ephemerality. The most unsustainable condition is the combination of high impact and short duration.

This is the critical problem of much contemporary event architecture: pavilions, stands, fairs, installations, institutional displays, cultural scenographies, biennials, festivals, and photogenic devices that use complex materials, transport, packaging, lighting, climate control, specialised assembly, and dismantling only to disappear shortly afterwards.

Such architecture belongs neither to the renewable logic nor to the permanent logic. It is not innocent enough to last only a short time, nor durable enough to justify its impact. It is the worst hybrid: high cost, brief life, rapid waste, and aesthetic justification.

It is born already as deferred waste.

Ephemeral architecture is justified only in two cases: when it is materially almost innocent, or when it fails as ephemeral architecture, that is, when it proves that it deserved to remain. If it meets neither condition, its temporariness is not a virtue, but waste.

6. A Temporal Matrix of Sustainability

Architectural sustainability should be evaluated through a temporal matrix. It is not enough to classify materials as good or bad. Their behaviour over time must be analysed.

A serious matrix should consider:

- initial impact;
- embodied carbon;
- capacity to store carbon;
- expected duration;
- replacement frequency;

- repairability;
- maintenance;
- possibility of dismantling;
- final material fate;
- persistent social need;
- limited adaptability;
- institutional custody;
- climate resilience;
- capacity to prevent future demolitions and reconstructions;
- expected ROE over different time horizons.

According to this matrix, a straw building may be superior to a concrete one if its cycle is clean, local, renewable, and materially honest. But a concrete building may be superior to a straw one if it lasts for many centuries, prevents multiple reconstructions, and maintains a relevant function. And stratified architecture may be superior to both if it combines renewable skins with permanent cores.

Sustainability is not an aesthetic property. It is a temporal relationship.

7. The Paradox of the Climatic Future

Climate change introduces an additional difficulty. The future may not reward rigid permanence, but continuous adaptability. In a world of extreme temperatures, migration, scarcity, floods, fires, changes of use, and energy crises, perhaps only architectures capable of constant change will survive.

But this possibility should not be celebrated too quickly. If only the adaptable can survive, perhaps we are not witnessing the triumph of adaptability, but the defeat of permanence. Perhaps durable buildings were not mistaken; perhaps humanity has produced a world in which the promise of duration becomes unviable.

If permanence has no place, then nothing has any guarantee of permanence. Not even human beings.

Permanence has never been an absolute certainty, but a rational aspiration. No human work can promise eternity, just as neither can those who build it, the civilisation that safeguards it, or the human species itself. Precisely because nothing possesses a guarantee of permanence, aspiring to the greatest possible duration is not a metaphysical promise, but a strategy against deterioration and waste.

For centuries, many rigid and only slightly adaptable architectures have remained. Temples, bridges, walls, aqueducts, monasteries, cathedrals, stone houses, and entire cities have endured political, religious, economic, and technical changes. They did not survive because they were infinitely flexible, but because their form, matter, use, or value justified their care.

If we can no longer promise duration, the question is not only architectural. It is civilisational.

What have we done for architecture to no longer be able to aspire to remain?

8. Conclusion: Three Material Futures

Future architecture cannot limit itself to choosing green materials. It must choose temporal regimes. It may be renewable and carbon-sinking if it accepts brief but materially honest cycles. It may be ultrapermanent if it turns extreme duration into the justification of initial impact. Or it may be stratified if it rationally organises layers of different duration within the same work, adapts each one to its function, and allows the whole to respond to a changing environment without unnecessarily compromising the permanence of the structural core.

What it can no longer be is materially costly and temporally frivolous.

Architecture made of straw, timber, or plant fibres is justified only if its ecological cycle is real. Architecture made of concrete, stainless steel, stone, or ceramics is justified only if it aspires to last. Stratified architecture is justified only if each layer knows its time.

The sustainable future will not simply be made of timber, straw, concrete, or steel. It will be made of architectures capable of answering for their duration.

Because time is not external to sustainability.

Time is its test.